XXI.

ON THE METHODS OF STUDY OF THUNDER-STORMS.

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During the past summer the New England Meteorological Society undertook a special series of observations on thunder-storms, and while preparing the blanks and studying the records there has been occasion to examine similar investigations elsewhere, from which it appears that there is some diversity as to matter of observation and method of discussion. In order to make the contrast among the several systems better understood, I may first state briefly the peculiar features of thunder-storms, and then explain why a special service of numerous volunteer observers is needed to detect their structure and mechanism.

General Phenomena of Thunder-storms.— In the first place, many of the thunder-storms that pass over us are so small that they easily slip between the Signal Service stations, without even being heard there. Such a one was the violent thunder-squall of July 21, 1885, that came early from New York, and traversed New England at the rate of nearly fifty miles an hour; it crossed the Hudson about eight o'clock in the morning, quite unobserved from New York City or Albany; it ran along eastward on the northern boundary of Connecticut, passing north of New Haven and New London, and south of Boston, probably in sight from these stations, but too near their horizon to attract attention; finally, it crossed from Plymouth to Provincetown, Massachusetts, and went out to sea about half-past one o'clock, and was heard of no more. It would have been practically unknown, had not our observers determined its path by means of their fifty odd reports.

Larger thunder-storms stretch in long, narrow belts over a considerable distance, advancing sideways or obliquely across the country. These often enough pass over the Signal Service stations, but, even if fully observed there, many of their most characteristic features would remain undetermined. Besides, the observers at the signal offices have much routine work to do, and cannot well be called upon to perform extra and irregular duties. The considerable amount of non-

instrumental observation that a fully developed thunder-storm needs, may be inferred from the following description of the phenomena accompanying such a storm, while passing through the storm-belt at right angles to its length. The earliest forerunner of the storm is the high cirro-stratus overflow, reaching far ahead of the rain: as this rises above the western horizon, the outlines of massive gray "thunder-heads," or cumuli, appear beneath it; they reach to a great height, and are seen towering aloft as they approach. Towards the base they are very dark; but often at the lower front margin of these heavy clouds there appears a ragged fringe of gray squall-cloud, much agitated, and below this is the falling rain. All these clouds should be examined to detect their motion and growth. As the storm comes nearer, and the thunder grows louder, the wind squall may sometimes be recognized in the distance by the dust that it raises; it strikes suddenly, often with destructive force, and quickly passes on as the rain begins. This squall is not an invariable accompaniment of thunder-storms, and it is yet to be determined why it is sometimes present, sometimes absent. The temperature falls rapidly as the rain comes; for the temperature of the rain, and especially of the hail that often accompanies it, is much lower than that of the air. Much is hidden now by the falling rain, but, as it passes, the lower clouds appear and rapidly break away, showing brighter clouds or clear sky and sunshine in the west. The high cirro-stratus is then seen on the rear of the storm: it often shows the curious festoon-clouds on its lower surface. As the sky clears, the temperature returns towards its normal value.

The altitude, dimensions, and motion of all these many parts manifestly offer plenty of material for systematic study; and all weather services agree that many observers are needed in such work. The average distance between the stations must be a small fraction of the dimensions of the storm, or else features of importance may escape notice.

Plan of Observations. — In laying out the task for the volunteer assistants, no predetermined hours for occasional synchronous observations can be found that serve well in this work; times set before hand would too often fail to catch the swiftly passing storms. Records must be made chiefly at times announced by the storms themselves. It would take the greater part of an observer's attention for the two or three hours of a storm's passage to detect and record all its noteworthy peculiarities, and this is much more time than most volunteer observers can give. But the interest, time, opportunity, and ability of observers are so varied, that what is easily accomplished by one is far out of reach of another. We have therefore given detailed instructions to the

better, more devoted observers, so as to lead them on to their own improvement as well as to ours; while we have offered only the very simplest form of record to those who are willing to do something, but who are unable to do much, or who would be discouraged at the sight of a page or more of printed explanations. So far as I know, no other services thus classify their observers: this cannot be because they have enough of the highest class to serve all their needs, for their observations are generally very elementary as to material, and in many cases are insufficient in number. Doubtless it would be best to have all observers of one uniform and high standard; but this is quite out of the question in a volunteer service. Our observers were therefore divided into three classes last summer, and, in attempting the work again this year, it seems best to separate the classes still further; not by having more than three classes, but by reducing the demands on Class A, and by asking for more from those whom last summer's work has shown to be painstaking and close observers.

Before comparing the observations on special phenomena desired by different services, another point may be mentioned which is, I believe, peculiar to the instructions of our New England Society. This is the attempt to obtain material for synchronous maps of storms, without announcing beforehand the hours for observation; and although it did not fully succeed, from lack of observers, it may be regarded as a distinct improvement, and one well worth retaining in a second year's work. Observers of Classes B and C were asked to take record of temperature, wind, &c., every *even* half or quarter hour *during the storm.* This is a heavy task, but in return it gives us data for the construction of numerous synchronous maps at short intervals, showing not simply the inferred advance of the storm-belt, but the actual attitude of all the accompanying phenomena for the several times of record. The advantage of taking hours thus marked out by the storm over any hours appointed before hand is apparent at once; and the importance of the method may be estimated by considering the great advance that was accomplished when it was introduced in the study of cyclonic storms.

In deciding what elements of the storm shall be observed most fully, it must be first agreed by what feature the advance of the storm shall be defined. In Italy, Ferrari places the storm by the attitude of its "maximum phase" where the thunder is loudest. In Bavaria, Von Bezold takes the time of the first thunder for his guide, and draws "isobrontal" lines through points where it is heard at the same time. The first rain has thus far been used in our reductions, and with very

satisfactory results. Evidently the storm front, however determined, must be defined by a feature easily recognized by all observers; for the usefulness of the relatively few detailed records of the higher class observers depends largely on the accuracy with which they can be placed in their proper position with respect to the storm front, as determined at numerous stations by the simple records of the lower class. It is therefore an important matter to choose what shall be adopted as the guide-observation, as this defines the simplest task that can be set.

The time of first audible thunder is not satisfactory. It comes without warning; it is faint; it is not equally perceptible to observers in different situations; even if well observed, it measures a variable distance from the storm-belt, for the flashes that cause the thunder must be of unequal intensity; finally, it is too distant a product of the storm, and should be replaced by something more immediately connected with the line of action. As a guide, it therefore does not seem serviceable. In storms where no rain reaches the ground, the first and loudest thunder-claps are of value; but such storms are exceptional, and of small importance.

The last thunder is a troublesome thing to note, and it will probably be omitted in the coming summer. The loudest thunder is very useful as a mark of the middle belt, but it is not always accurately definable; still, it is almost or quite as good a guide as the first rain. But thunder has its chief value in calling the observers to their work; as soon as it is heard, record it, and then watch for what follows.

The rain front in well-developed storms is on the whole, I believe, the best guide to their advance across country. The observer is generally on the watch for its arrival, as the thunder in nearly all cases precedes it. It can often be seen coming just before its arrival, and, thus prepared, the observer may note its time within half a minute without difficulty. Even if no thunder is heard before it, the darkening approach of the rain clouds is generally sufficient to call one's attention from other occupation. The following records show the measure of agreement that may be expected. They are taken from stations in northeastern Rhode Island, where observers were close together.

In the first example, a loud thunder-clap evidently called the attention of all the observers, and in that case gave more closely accordant records than the time of first rain. In the second example, the stations are arranged almost in geographic order, and show an excellent sequence of rain times. The agreement is indeed exceptionally good.

July 9.

		First Thunder.	Rain.	Loudest Thunder.
Pawtucket,		5.52	6.03	6.47
Providence,	*a*,	5.41	6.05	7.03
	b,	6.15	6.10	7.00
	c,	6.20	6.12	7.00
	d,	6.—	6.08	7.02

July 21.

Woonsocket,		12.00	12.20	12.24
Ashton,		11.50	12.25	12.20–12.40
Pawtucket,	*a*,	12.15	12.27	12.31
	b,	12.17	12.29½	12.35
Providence,	*a*,	12.19	12.27	12.35
	b,	12.05	12.28	12.34
	c,	12.08	12.28	12.25
	d,	12.15	12.30	12.38
	e,	12.—	12.30	12.35
Silver Spring,		12.11	12.35	——

Methods of Observation elsewhere. — We may now consider the demands made upon observers by various services where the systematic study of thunder-storms has been undertaken: at the same time, a few notes are added on the general standing of the work in several countries.*

FRANCE. System founded by Leverrier in 1865; reductions in charge of Fron, and now published in the *Annales du Bureau central météorologique.* As an incentive to observation, a large number of maps illustrating the paths of certain storms were distributed to the observers during the first season's work. I do not know how far this practice has been continued. There have been over one thousand observers in recent years.

Observations: time of first, loudest, and last thunder; direction of storm's appearance and disappearance; velocity and direction of clouds; force and direction of wind; intensity of lightning, thunder, rain, hail; direction of distant lightning; general notes on the appearance of the storm, and on its injurious effects.

Intensity is expressed on a scale of six; direction is observed to octants. The records are made on a quarto page, and are sent free, folded but not sealed, through the mail, to the departmental prefects, by whom they are discussed before finally going to Paris.

* I am indebted to Mr. A. Lawrence Rotch for opportunity of examining his collection of "forms" for observation, from which many of these notes are taken.

NORWAY. Observations were begun in 1867 under the direction of Professor Mohn. The results are published in the *Videnskabs Forhandlinger*, at Christiania, beginning in 1868. An abstract of them in French (from which these notes are taken) is given in certain volumes of the *Atlas météorologique de l'Observatoire de Paris.* In 1868 there were 270 observers.

Observations: time of begining and end of the storm; its first and last direction; the direction and velocity of wind and clouds; the intensity of lightning, thunder, rain, and hail; remarks on the damage caused by the storm.

RUSSIA. The study of thunder-storms in this country was initiated in 1871, by the Imperial Society of Geography. The observations are reduced by Klossovski, Professor in the University at Odessa, who has published a memoir thereon in Russian, and an abstract of it in French, *Les Orages en Russie*, Odessa, 1886. I have seen only the latter: it does not contain statistics as to the number of co-operating observers.

Observations: no instruments required; time of beginning and end of the storm; direction of first and last appearance; intensity of lightning and thunder; intensity and duration of rain and hail; direction and velocity of wind and clouds.

BELGIUM. Observations were begun on a small scale in 1867, and extended in 1877 to over eighty observers. The reductions have been made by A. Lancaster, and published in the *Annales de l'Observatoire Royale de Bruxelles;* also in abstract in the *Annuaire*, issued by the same observatory.

Observations: the plan of work is very similar to that followed in France.

ITALY. Schiaparelli began the systematic study of thunder-storms in Northern Italy in 1877, the results appearing in the publications of the Royal Observatory of Brera, in Milan. In 1880, the work was taken in charge by the Central Meteorological Office in Rome, and extended over all parts of Italy; the observations for 1880 and 1881 are discussed in great detail by Dr. Ciro Ferrari, and form heavy quarto volumes in the *Annali della Meteorologia*, with numerous maps and diagrams.

Observations (in later years): beginning and end of the storm, and its "maximum phase"; direction of its motion; direction and force of winds; intensity of thunder, lightning, rain, and hail; extent of sky covered by storm; if the observer have instruments, records are desired of rain-fall, temperature, humidity, and pressure.

Records are made on franked postal cards, that are sent first to the meteorological station in the chief town of the province, and afterwards forwarded to Rome.

BAVARIA. Observations begun by Von Bezold in 1879; aided after 1880 by Von Schoder in Würtemberg. The results are published, with other records of the Bavarian service, in the *Beobachtungen der meteorologischen Stationen in Baiern.* In 1879, 279 observers took part in the work, and 252 in 1882; after the first year about 60 observers were added in Würtemberg.

Observations: time and direction of heat-lightning; time of first and last thunder, rain, and hail; direction of storm's advance; direction and strength of the wind before, during, and after the storm; notes on damage caused by the storm. Reports are made on franked postal cards.

NETHERLANDS. Work directed by the Royal Meteorological Institute at Utrecht; observations in charge of, and reduced by Snellen; about three hundred observers in 1884.

Observations: distance of the storm; time of the first, loudest, and last thunder; direction and velocity of clouds; direction and force of the wind before, during, and after the storm; time of first and last rain and hail, and their strength; damage by storm.

Intensities on scale of five. The record is made on a quarto page, that goes free through the mail.

SAXONY. Study of thunder-storms instituted by Bruhns in 1880; now directed by Schreiber at Chemnitz.

Observations: time and direction of first appearance of storm, and of first and last lightning, thunder, and distant rain; time of first and last local rain and hail; time and direction of clouds (kind not specified) passing zenith, or direction of their motion if they do not reach zenith; wind before, during, and after the storm. A special card is provided for record of hail-storms.

CENTRAL GERMANY. Observations made by the *Verein für landwirthschaftliche Wetterkunde,* under the direction of Assmann, beginning in 1880. The results appear in a pamphlet, *Die Gewitter in Mitteldeutschland,* by Assmann. There were over two hundred stations the first year, and about six hundred in 1885.

Observations: direction and intensity of storm; time of first and last thunder, and its intensity; many notes on appearance, direction (up, down, or horizontal), and form of lightning flashes, and on lightning strokes; time of first and last rain and hail, with their amount; direction and strength of wind before, during, and after the storm; notes on dust-squall preceding the storm.

Intensity on a scale of three (0, 1, 2); wind force on scale of twelve. No temperature records. Especial attention is given to the appearance and effects of lightning. Reports are made on postal cards.

SWITZERLAND. Observations systematically begun in 1883; reduced by Mantel and published in the *Annalen der schweizerischen meteorologischen Central-Anstalt.* About 140 stations besides the regular stations of the Swiss weather service. 2,689 reports in 1883.

Observations: time of first and last thunder; of passage over zenith; of beginning and ending of rain and hail; direction of storm's origin and disappearance; direction and force of wind before, during, and after the storm; notes on rain-fall and damage by storm.

Intensity on a scale of six; direction recorded to octants; no observations of temperature. The records are made on franked postal cards.

UNITED STATES SIGNAL SERVICE. Investigation of thunder-storms by volunteer observers, organized by Prof. H. A. Hazen in 1884; records of more than 13,400 storms were obtained for this year, and a report thereon is to be sent to all observers.

Observations: thunder, first, loudest, and last; direction of storm, coming from and going to; time of first and last rain and hail, and amount; direction and force of wind before and after storm; distant lightning; and remarks.

"Thunder-storms twelve hours apart may be taken as separate storms." Intensities on scale of five. Reports are made on a special "penalty card," addressed to the Chief Signal Officer of the Army.

In reviewing the requirements thus summarized, the absence of a sufficient correlation of the several objects of observation, and the general omission of temperature records, seem to me serious defects in the plan of work. Certainly the relation of temperature to wind, of surface wind to cloud-motion, of wind and clouds to rain, etc., can be much better determined if at certain times records are taken of *all* of these different phenomena. We have therefore aimed to secure observations of wind, temperature, rain, clouds, etc., all together, several times during every storm; the times being determined by the occurrence of the first thunder, the first wind-squall, the first rain, the loudest thunder, and the last rain; and also by the even half or quarter hours, as already described. Our records as proposed for the coming summer may therefore be thus summarized.

Summary of Instructions to New England Observers. — *Class A.* — *Required:* time and direction of first and loudest thunder, whether rain falls or not; time of first, heaviest, and last rain, and estimated amount, whether with thunder or not; intensity of storm on scale of

five. *Requested:* time and amount of hail; time and direction of heat-lightning; notes on wind.

Class B. — *Required:* time and direction of first and loudest thunder; temperature, wind (force and direction), and sky *at time of first thunder*, and then every even half or quarter hour (e. g. 3.00, 3.30, 4.00, etc.) as long as thunder is heard; time, direction, and force of wind-squall, and its temperature; time of first, heaviest, and last rain, its estimated amount, and temperature of air at its beginning and end. *Requested:* notes on violence of rain at various times; frequent observations (even every minute) of temperature during squall; heat-lightning, lightning strokes, and notes on clouds.

Class C. — In addition to the requisitions in Class B, observations are here desired on clouds; first appearance and motions of cirro-stratus, cumulus, squall-cloud, festoon-cloud; appearance of distant storms; determination of growth or dissolution of clouds by watching changes at their margins; angular altitude and direction of same clouds from time to time as storm approaches, giving basis for determination of altitude when velocity is known; sketches of clouds; self-registering instrument of some kind, and observations of humidity; photographs of clouds and lightning.

It is not intended that Classes B and C should be rigidly divided; slight changes can be made at the observer's pleasure, but every one must do at least the requirements of Class A. Change of station is also permitted, as we thus gain more than we lose; but permanent residence through the summer is desirable.

It is often nearly as important to know that a storm did not appear at a certain station, as to have a record of it. It is therefore proposed to ask all observers to keep a very simple journal, stating for every day merely whether it was clear, fair, cloudy, rainy, or stormy, and sending in this record at the end of every month. This will insure continuous record, and will at the same time give data for the sharp limitation of storm areas; actual denial of storm being much safer for this purpose than simple absence of report.

I am well aware that the tasks here set are rather severe, but the experience of last summer justifies the expectation that they will be well borne. There is no question whatever that every post-office town in New England contains residents fitted and ready to undertake the records of Class A; the difficulty that we encounter is not in persuading them to do the work, but in finding the right persons. An essential in the scheme is therefore a much greater notoriety than is needed in most scientific investigations; for this we count largely

on newspaper notices, on circulars to members of our society, and to co-operating observers, and in some cases on circulars to postmasters; but in this day of many circulars, they give an uncertain dependence. Members in Classes B and C are enlisted directly or by promotion from A, and include many careful observers, whose interest in the society is a great gain in its work. Indeed, our relation to a body of intelligent correspondents, thus enrolled in all parts of New England, is a most valuable assistance in a variety of ways. We can at any time address them on special questions, and feel fairly sure of interested attention to our requests: for example, in a recent attempt to trace out the limits of an earthquake in southern New Hampshire, I have had much assistance from our volunteer observers of thunder-storms. At the same time, we may feel that the attention thus awakened to matters of a scientific nature constitutes one of the results that we desire to reach; for in the constitution of our society its object is announced to be "the cultivation of meteorological science in New England."

Discussion of Observations. — Until the systematic observations were begun in France, most investigations of thunder-storms were devoted to studying their electrical action, to the neglect of their mechanism. This was much as if a physicist should carefully examine the peculiarities of electric sparks, but neglect to study the construction of the machine that produced them. There were, of course, exceptions to this practice, but they were distinctly exceptions. Since the establishment of systematic observations, it has generally been customary to present their results in the form of averages of occurrence according to months, hours, and places; also in averages of direction and velocity of motion, and attitude with respect to the neighboring and controlling centre of low pressure; and again in maps that represent the path of the storm across the country. But while these statements are of much value and interest, they generally consider the storm only as a whole. More detailed study is required to determine the relation of the different parts of the storm, the mechanism of its winds, the distribution of its temperature, pressures, clouds, and electrical phenomena. Some may, however, say, on first approaching this question, Do thunder-storms possess sufficiently persistent features to admit of a regular classification of their parts? The results of European observations — and especially of those discussed by Dr. Ferrari of Rome — answer this question very definitely in the affirmative. We know that cyclonic storms have been found susceptible of detailed dissection, and that their several parts appear with much regularity in

successive storms. Much valuable work has been done of late years in thus showing the average distribution of the meteorological elements in areas of low pressure. A similar work needs yet to be carried to completion for thunder-storms.

Three observations a day are sufficient to define the slow weather changes of the large cyclonic storms; but in thunder-storms observations should be taken every fifteen minutes at most, that is, at the rate of ninety-six times a day, so rapid is the motion of these storms in comparison to their size. A simple method of portraying a storm, thus observed at numerous stations, would be the construction of synchronous maps of all its elements: thus the storm as a whole is seen passing over the country. But even then it is not easy to bring all the details of many maps into a single mental picture; and, moreover, the unfortunate lack of observations must for some time yet make these separate maps very imperfect. Some method of *composite portraiture* is needed that shall throw all the observations into their proper position with respect to some controlling line, such as the storm-front, and at the same time allow the records of one station to supply the deficiencies of another. I have attempted to accomplish this in the following way. The attitude of the storm-front (rain-front) is first determined by charting all the times of rain beginning, and drawing lines to show the position of the front for every even quarter of an hour; the direction and velocity of advance are also thereby determined, and generally, in the best developed storms, a certain line may be chosen to represent the middle path of the storm: the average line of rain-front and the middle path are taken as axes of co-ordinates; time intervals before and after the rain beginning serve as abscissas, while distances north and south of the middle path are ordinates; and the ratio of abscissas to ordinates is known as soon as the average velocity of storm progress is determined. The axes thus chosen are next drawn on a sheet of tracing-paper: now if this sheet be laid upon a map of the region traversed by the storm, and moved along in the direction of the storm's advance (the line of middle path being coincident on the two), it (the tracing-paper) may be taken as representing the storm stratum on its way across the country: every station that furnishes a record may be imagined to trace a line on the storm stratum about parallel to the middle path, and intersecting the rain-front to one side or the other of the middle path, at a distance from it measured by a positive or negative ordinate; and all observations can be placed somewhere on the lines thus traced, their distance in front or behind the rain-front being measured by positive or negative

abscissas. In practice, a simple method of proceeding is adopted: lines are drawn on the storm stratum (tracing-paper) to represent the path of every station through the storm, and the name of the station is written at one end of its line: then a time scale is prepared to measure the abscissas, its unit being the average distance traversed by the storm in an hour; for a storm moving from west to east, as is the general rule, the scale is numbered from right to left; it is next laid on a certain station line, parallel to the middle path, and placed so that the time of rain beginning for this station falls on the rain-front line; then all the observations from that station can be marked down opposite their proper hour and minute on the time scale, and they will thus fall in their proper place in the storm. After plotting a good number of reports in this way, the composite portrait shows that the area an hour or so in front of the rain is occupied with records showing high temperatures, clear sky with clouds from which thunder is heard rising in the west; gentle winds, as a rule from a southerly quarter; nearer the storm the clouds cover more of the sky, and the temperature falls a little; close in front of the rain the wind-squall appears, blowing out from the storm; as the rain is reached, the wind dies away, the temperature falls rapidly, the thunder grows louder, and lightning strokes appear; half an hour or more, with rain still falling gently, the western clouds break up, and blue sky appears; the temperature rises slowly, and the thunder dies away as the storm moves off; and rainbows appear on its back as the sun shines out. It soon becomes evident that there is really a systematic distribution of certain elements of the storm that are susceptible of legitimate averaging; and from their graphic representation in the composite portrait, the proper areas and intervals for averaging may be chosen. In this way, the fullest use may be made of the most varied records.